

IN SITU FATIGUE LOADING STAGE INSIDE SCANNING  
ELECTRON MICROSCOPE

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ABSTRACT

A fatigue loading stage inside a scanning electron microscope (SEM) has been developed at the NASA Lewis Research Center. The stage allows dynamic and static high-magnification and high-resolution viewing of the fatigue crack initiation and crack propagation processes. The loading stage is controlled by a closed-loop servohydraulic system. Maximum load is 1000 lb (4450 N) with test frequencies ranging up to 30 Hz. The stage accommodates specimens up to 2 in. (50 mm) in length and tolerates substantial specimen translation to view the propagating crack. At room temperature, acceptable working resolution is obtainable for magnifications ranging up to 10 000X. The system is equipped with a high-temperature setup designed for temperatures up to 2000 °F (1100 °C). The signal can be videotaped for further analysis of the pertinent fatigue damage mechanisms.

The design allows for quick and easy interchange and conversion of the SEM from a loading stage configuration to its normal operational configuration and vice versa. Tests are performed entirely in the in situ mode. In contrast to other designs, the NASA design has greatly extended the life of the loading stage by not exposing the bellows to cyclic loading.

The loading stage has been used to investigate the fatigue crack growth mechanisms in the (100)-oriented PWA 1480 single-crystal, nickel-based superalloy. The high-magnification observations revealed the details of the crack growth processes.

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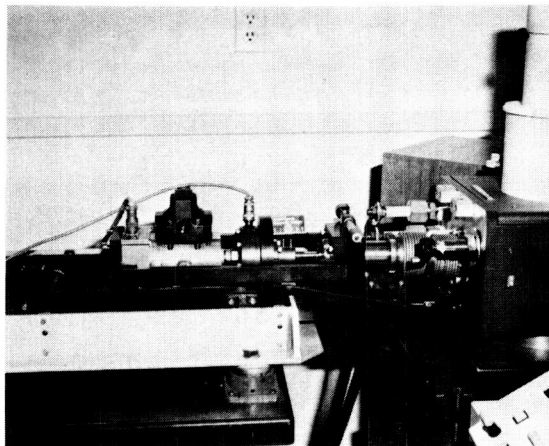
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## OVERVIEW

### MAIN FEATURES OF LOADING STAGE

Some of the main features of an in situ loading stage system developed at NASA Lewis are highlighted below. A photograph of the loading frame and some of the major system components are shown.

- o Dynamic observations of fatigue up to 10 000X
- o Loads up to 1000 lb; frequency up to 30 Hz
- o High-temperature capability
- o Interchangeable with normal SEM configuration



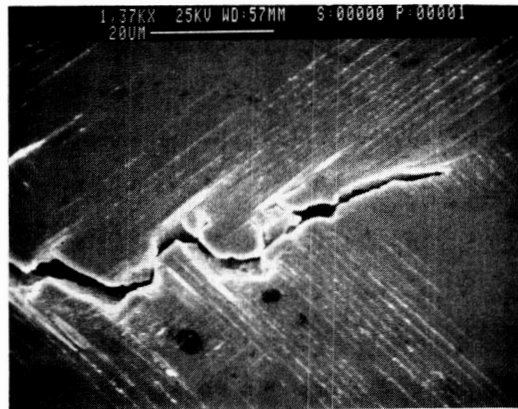
- DYNAMIC OBSERVATIONS OF FATIGUE UP TO 10 000X
- LOADS UP TO 1000 lb; FREQUENCY UP TO 30 Hz
- HIGH-TEMPERATURE CAPABILITY
- INTERCHANGEABLE WITH NORMAL SEM CONFIGURATION

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# SAMPLE FRACTOGRAPH OF SINGLE CRYSTAL

The fatigue processes in a PWA 1480 single-crystal, nickel-base superalloy were examined by using the loading stage system. Some of the major observations are described in this paper. The poster session includes a videotape presentation of the observed fatigue damage mechanisms. A sample fractograph is included below.



- FATIGUE PROCESSES IN PWA 1480 SINGLE-CRYSTAL, NICKEL-BASE SUPERALLOY
- FATIGUE CRACK GROWTH BY PLANAR SLIP
- CRACK CLOSURE AND SECONDARY CRACK BRANCHING
- VIDEOTAPE PRESENTATION OF FATIGUE IN A SINGLE CRYSTAL

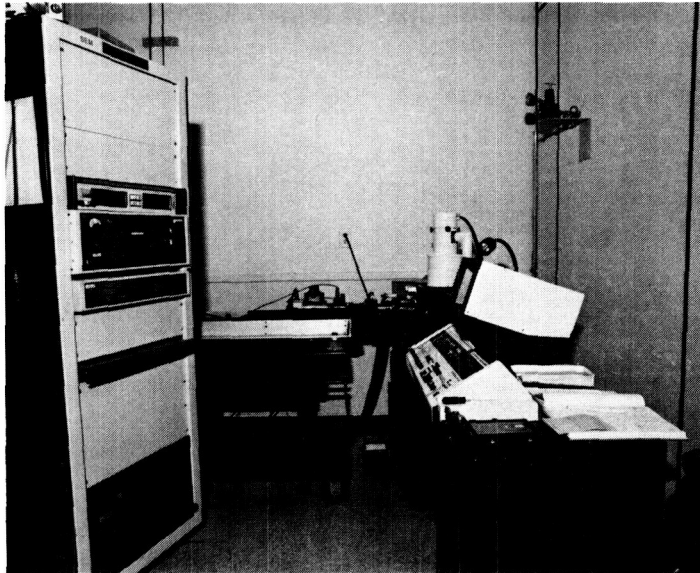
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## POSTER PRESENTATION

### LOADING STAGE

An overall view of the loading stage, the scanning electron microscope, and accessories is shown below. On the right is the SEM, in the center is the loading frame mounted on a four-wheel adjustable height cart, and to the left is the console housing the controls for the servohydraulic system and the high-temperature equipment. Not shown in the figure are the color monitor and the video tape recorder, which are also part of the system.

During the operation of the in-house designed loading stage, the regular SEM chamber door and the attached specimen stage are swung out of the way. If the loading stage is no longer needed, the entire assembly is rolled away on the service cart and the regular specimen stage is swung back into its normal operating position. This interchange is quick and easy, typically being performed in only 2 to 3 minutes.



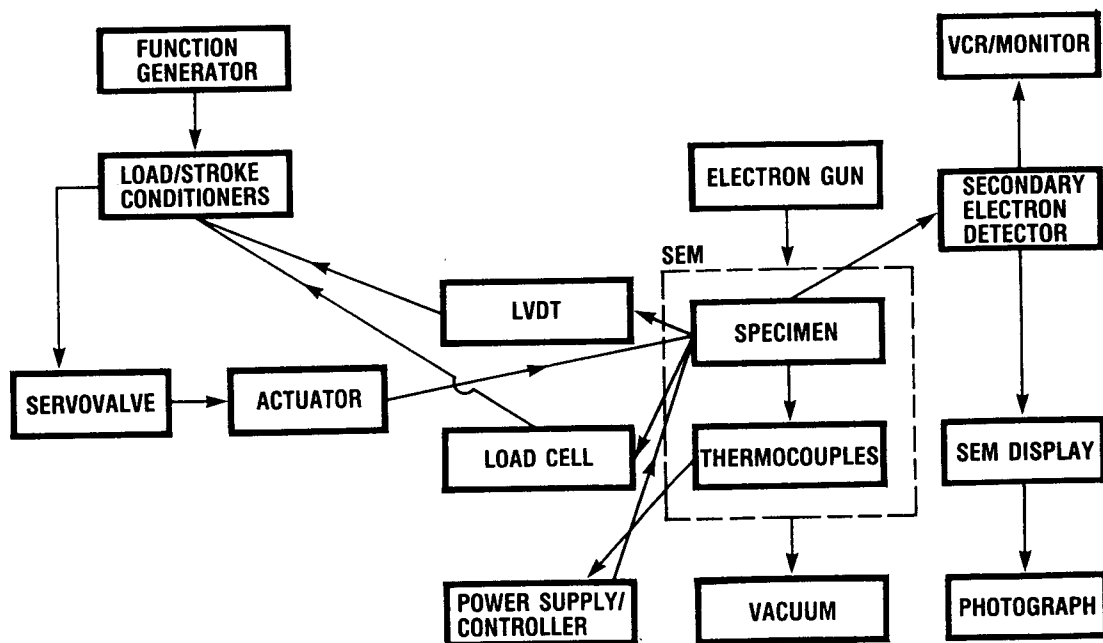
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# SCHEMATIC OF LOADING STAGE

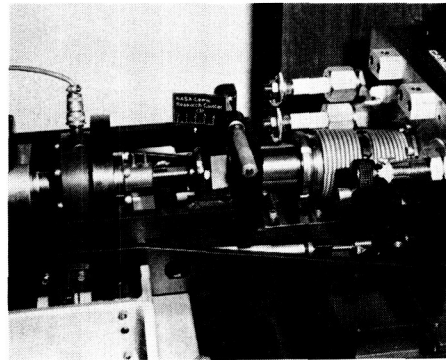
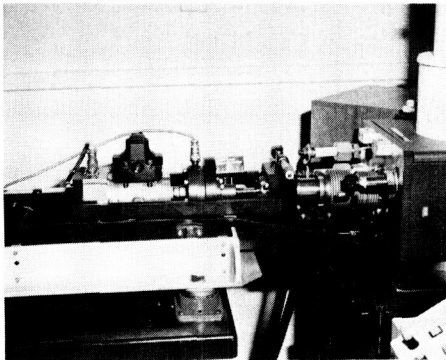
The entire loading stage system is shown here in schematic form. The system can be operated either in load or stroke control. The closed-loop servohydraulic portion of the system consists of a function generator, load and stroke conditioners and transducers, and a servovalve mounted to an actuator. The high temperature is achieved by passing a high current directly through a heating element surrounding the specimen. The current is applied from a dc power supply and controlled through standard means. The signal emanating from the specimen in the SEM can be sent to either a Polaroid camera or a video cassette recorder.



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## LOADING FRAME AND COMPONENTS

Detailed views of the loading stage are shown below. A 1-in. (25-mm) full-stroke axial actuator is attached to the loading frame. The actuator is driven by a 1-gal/min (4-liter/min) servovalve. Other components such as the load cell and the linear variable-differential transformer (LVDT) are attached to either the actuator or the loading rod. The entire assembly is connected to a support frame by two precision x-y translation stages and is also connected by a flexible bellows to a specially machined SEM door. The specimen is translated in the x and y directions by turning the micrometers mounted to the two translation stages.



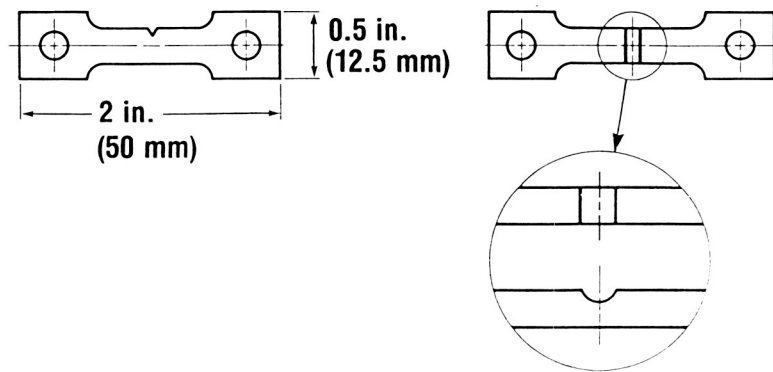
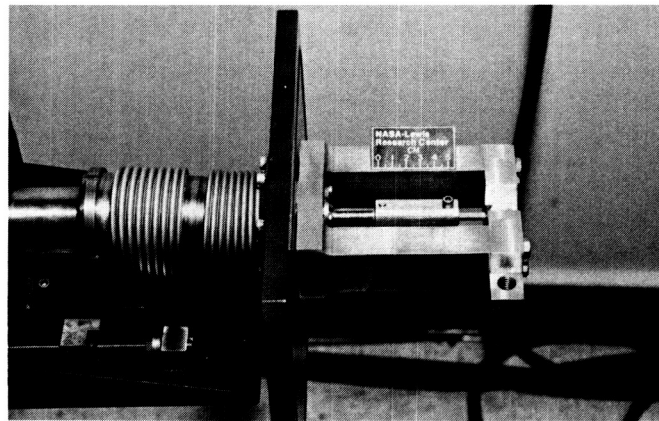
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# GRIP FIXTURES AND SPECIMEN

The specimen is mounted in the grip fixture as shown in the photograph. The setup illustrated below is for room-temperature testing only. The simplicity of the room-temperature setup allows for a reduction in the working distance to 0.8 in. (20 mm) and this significantly increases the maximum useful resolution of the image.

Two examples of the type of specimen geometries used to date are shown below. Other configurations are possible because the allowable specimen viewing area is 0.7 by 0.7 in. (18 by 18 mm).



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## PERFORMANCE CHARACTERISTICS AND SPECIFICATIONS

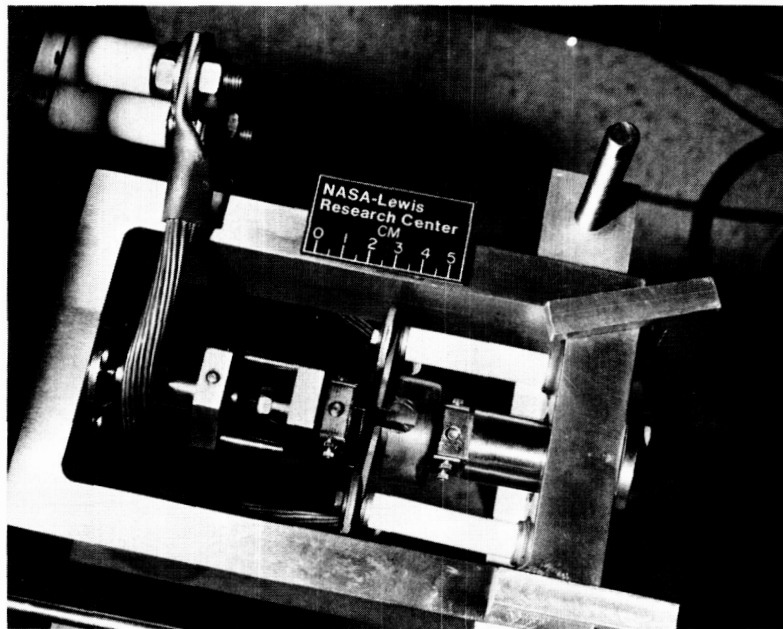
The design of the NASA Lewis in situ loading stage offers a number of important advantages. Because the bellows are not exposed to fatigue loading, long-duration tests can be performed in the in situ mode. Testing can be performed over a wide range of frequencies and temperatures. The system is also easily interchangeable with a normal SEM configuration. No other existing design has all of these advantages.

MAXIMUM CYCLIC LOAD, lb (N) .....	1000 (4450)
MAXIMUM CYCLIC RATE, Hz .....	30
MAXIMUM TEMPERATURE (DESIGNED), °F (°C) .....	2000 (1100)
USEFUL MAXIMUM MAGNIFICATION	
ROOM-TEMPERATURE STAGE .....	10 000X
HIGH-TEMPERATURE STAGE .....	3000X
WORKING DISTANCE, mm	
ROOM-TEMPERATURE STAGE .....	20
HIGH-TEMPERATURE STAGE .....	55
VIEWING AREA, in. (mm) .....	0.7 BY 0.7 (18 BY 18)

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# HIGH-TEMPERATURE SETUP

High-temperature operation is achieved by resistance heating of a cylindrical tantalum element surrounding the specimen. The power is supplied by a 625-A-maximum-current controlled dc power supply. The specimen is heated by radiation from the heating element. The cylindrical heating element is designed with a slit that enables the electron beam to impinge on the specimen and permits the escape of secondary electrons to the SEM collector. The heat is removed from the system through a water-cooled loading rod, and the SEM components are protected from overheating by three tantalum shields. Six thermocouples monitor the temperature of the specimen as well as the temperature of the critical SEM components.



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## PLANAR SLIP IN PWA 1480 SINGLE CRYSTALS

The fatigue loading stage has been used to investigate fatigue crack propagation mechanisms in (100)-oriented PWA 1480 single-crystal, nickel-based super-alloy specimens. The fractographs reveal that the mechanism by which the crack propagated consisted of planar slip on two different slip planes. The slip planes were identified later to be  $(1\bar{1}1)$  and  $(\bar{1}11)$ . The fractographs also make it possible to measure crack tip opening displacements and the extent of damage occurring ahead of the crack tip.



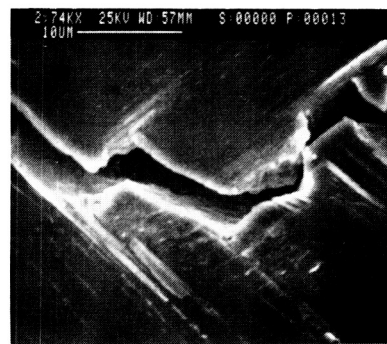
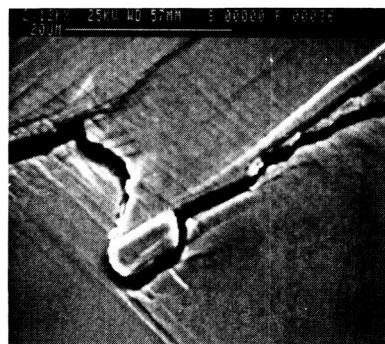
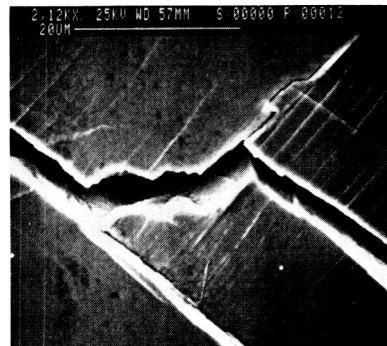
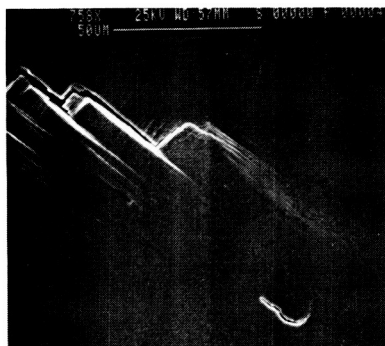
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# DAMAGE AHEAD OF CRACK TIP AND CRACK CLOSURE

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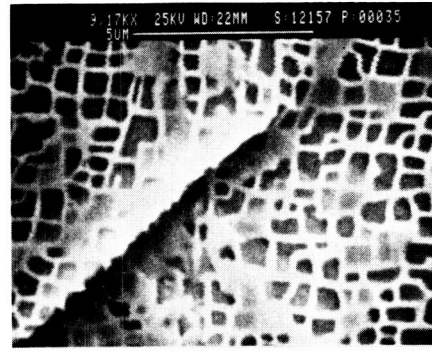
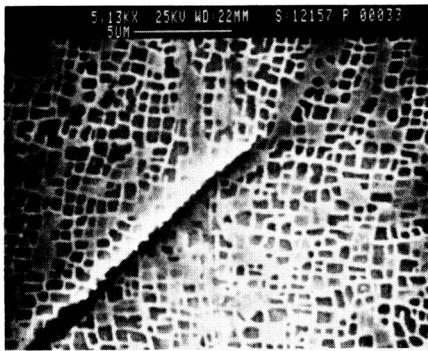
Observation of the fatigue damage processes in PWA 1480 single crystals reveals cracking ahead of the crack tip and the extent of the damage zone. The upper fractographs reveal the details of the damage occurring from planar slip as well as secondary branch cracking taking place between slip bands. The two bottom fractographs reveal regions of crack closure behind the crack tip even though the pictures were taken with the specimen under a relatively high axial tensile load.



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## INTERACTION OF CRACK WITH STRENGTHENING PRECIPITATES

High-magnification micrographs reveal the interaction of a crack in a PWA 1480 single crystal with the gamma prime strengthening precipitates. Instances of small-scale vibrations are noticeable at these high magnifications.



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